

Is the first annulus on the otolith of the Atka mackerel, *Pleurogrammus monopterygius*, missing?

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Atka mackerel, *Pleurogrammus monopterygius*, is a semidemersal, shallow-water species distributed along the Northern Pacific Ocean from the Kamchatka Peninsula to Southeast Alaska. Resource surveys show that the largest concentration of this species is along the Aleutian Islands chain where it sustains an important and growing commercial fishery.

Few studies (Gorbunova, 1962; Lee, 1985) have described the life history of Atka mackerel. Adults migrate to coastal areas from the open ocean before the July to October spawning season (McDermott and Lowe.¹). Hatching occurs about 40–45 days after spawning. Gorbunova (1962) reported that newly hatched larvae are about 8–10 mm long (whether measurements were standard or fork lengths was not indicated); whereas fish 60–70 mm and 170–190 mm long are 1 and 2 year olds, respectively. However, the smallest Atka mackerel observed with a single translucent zone on their otoliths were May-captured

180-mm-FL fish caught during bottom trawls in the Northwestern Pacific (Fig. 1). Because there are no other translucent zones visible on the otoliths, convention dictates that the one formed along the otolith margin represents the first-year annulus and that the fish is assumed to be one year old. The contrast in lengths at age between otolith-determined ages and Gorbunova's data has long vexed fisheries scientists.

The purpose of this study is to determine whether Atka mackerel form an annulus during the first year of life. Annuli are also referred to as translucent zones (or dark zones), observed on the otolith when viewed with reflected light. To accomplish this, we 1) identified the season of translucent-zone formation for Atka mackerel; 2) compared characteristics between otoliths from spring-captured Atka mackerel larvae and otoliths observed with at least one translucent zone; and 3) examined average seasonal lengths of Atka mackerel during the first four years of life.

Methods

Seasonality of translucent-zone formation

A monthly series of Atka mackerel otoliths was selected from a collection maintained by the Age and Growth Unit at the Alaska Fisheries Science Center (AFSC). Young fish otoliths (observed with 2 to 3 translucent zones) were chosen to minimize affects of age-related factors on the marginal increment formation. A lack of fall and winter collections limited our samples to 19 or 20 otoliths per month. Otoliths meeting our criteria of less than four translucent zones were available from all months except November and December.

The sample was assigned to an age reader to determine the marginal increment stage of each otolith. Otoliths were prepared by snapping each one along the dorsal-ventral plane and by passing the broken surface over a flame. The burnt surface was examined with a dissecting microscope and illuminated by reflected light. Marginal increment determination was made along the ventral proximal edge of the broken surface at 50× magnification.

The stages of marginal increment development were defined as follows: stage 1 = a translucent zone is forming along the otolith growth margin; stage 2 = area of opaque growth between the otolith growth

¹ McDermott, S. F., and S. A. Lowe. 1995. The reproductive cycle and sexual maturity of Atka mackerel (*Pleurogrammus monopterygius*) in Alaskan waters. Alaska Fisheries Science Center, Resource Ecology and Fisheries Management, 7600 Sand Point Way NE, Seattle, WA 98115. Unpubl. manuscr., 30 p.

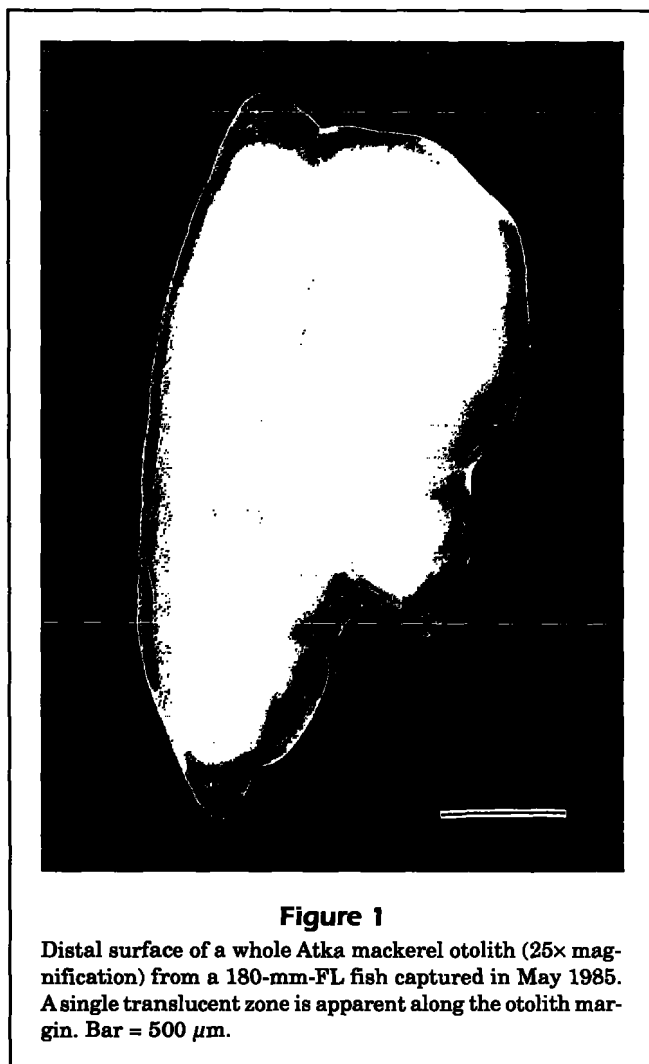


Figure 1

Distal surface of a whole Atka mackerel otolith (25× magnification) from a 180-mm-FL fish captured in May 1985. A single translucent zone is apparent along the otolith margin. Bar = 500 μm .

margin and adjacent translucent zone is nearly one-fourth the size of the previously deposited opaque zone; stage 3 = area of opaque growth between the otolith edge and adjacent translucent zone is nearly one-half the size of the previously deposited opaque zone; and stage 4 = area of opaque growth between the otolith edge and adjacent translucent zone is nearly equivalent in size to the previously deposited opaque zone.

Larval otoliths

In April 1993, the AFSC's Fisheries-Oceanography Coordinated Investigations (FOCI) scientists made a special collection of 88 larval Atka mackerel from one neuston-net trawl in the Akutan Pass region of the Aleutian Islands. Larval standard lengths were measured. Owing to the protocols of the different surveys, lengths cited in this study for fish smaller than 180 mm are standard length (SL) measure-

ments and lengths cited for fish equal or greater than 180 mm are fork length (FL) measurements.

Sagittal otoliths were extracted from 30 larvae and otolith diameters were measured. Each otolith was ground along one side of the sagittal plane until the otolith core was clearly visible through a compound light microscope at 1,000× magnification. Unvalidated but presumed daily increments were counted from the otolith core to the edge with a compound light microscope at 1,000× magnification.

Adult otoliths

To help distinguish between the larval and older fish samples in our discussion, we will refer to Atka mackerel >180 mm FL as adult fish. Otoliths observed with at least one translucent zone (250 mm FL–390 mm FL) were ground from both lateral sides until the core was visible on the surface when examined through a light microscope. Some otoliths were ground along the transverse plane and others along the sagittal plane. Unvalidated but presumed daily increments were counted from the core to the first translucent zone on 25 prepared otoliths with the clearest incremental patterns.

Five adult fish otoliths were prepared for viewing with a scanning electron microscope (SEM). These otoliths came from fish that were 250 mm FL to 280 mm FL and that had two translucent zones. Each otolith was ground from both lateral sides along the frontal plane until the core was visible on the surface when viewed through a light microscope. The samples were coated with platinum-palladium and examined with a Hitachi S-2300 SEM.

Seasonal length data

FOCI larval data Most larvae from this collection were captured in neuston nets (some from bongo-net tows) along coastal shelf zones around Kodiak Island (a few specimens were collected from the eastern Bering Sea). The survey years spanned from 1977 to 1986 and yielded larval length data from 1,545 specimens (Table 1) from September to November and from February to June.

The average seasonal lengths for northeastern Pacific larval Atka mackerel, calculated from FOCI data, were compared with Gorbunova's (1962) reported seasonal lengths for Atka mackerel larvae captured near the Kamchatka Peninsula. Gorbunova (1962) cited only monthly minimum and maximum lengths (assumed to be standard lengths) from September to May; therefore, for comparative purposes, we used the monthly midpoints.

Table 1
Standard length at catch date of FOCI Atka mackerel, *Pleurogrammus monoptygius*, larvae from 1977 to 1986.

Month	Year(s)	Sample size	Min length (mm)	Max length (mm)	Average length (mm)
Sep	1978	32	7.9	9.0	8.6
Oct	1977, 1978	171	7.8	14.7	10.0
Nov	1977, 1978	631	7.5	13.8	10.5
Feb	1979, 1986	198	9.1	19.6	14.4
Mar	1978, 1979, 1981	307	10.1	23.2	16.7
Apr	1978, 1981, 1984, 1986	198	11.2	32.8	19.2
May	1983, 1985	2	33.0	34.5	33.8
Jun	1979	10	27.9	44.6	34.7

NRIFSF offshore larval survey Twenty-five Atka mackerel, collected from 15-minute surface tows with larval nets (1.3-m diameter and 0.333-mm mesh size) in the central Bering Sea from 23 June to 20 August 1991 were provided by the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan. Standard lengths were measured. These fish were stored in formalin; therefore all otoliths from this sample were partially dissolved and unusable.

AFSC-RACE bottom trawl survey Average lengths of Atka mackerel observed with 1, 2, and 3 otolith translucent zones were calculated from data compiled by the AFSC's Resource Assessment and Conservation Engineering (RACE) division and taken from samples collected during the 1991 Aleutian Islands summer bottom trawl survey at depths ranging between 100 and 200 meters.

Results

Seasonality of translucent-zone formation

Translucent-zone formation along the otolith growth margin (stage 1) was the dominant edge-type observed on otoliths collected from January to June, reaching a 75% frequency peak in April (Fig. 2). Most otoliths exhibited the stage-2 pattern in July (90%) and the stage-3 pattern in August (65%). Stage-4 otoliths were most common in February (50%) and May (40%).

Larval otoliths

The April collection of larval Atka mackerel ranged in lengths from 10 mm SL to 23 mm SL and averaged 17 mm SL. Average otolith diameter was 240 μm .

No evidence of accessory primordia was observed in any larval otoliths. Daily increments surrounding the otolith core were narrowly spaced and many daily increments could easily have been missed. In some areas, distinction between increments was not clear (owing to poor contrast) so that estimating the number of increments in these areas was necessary. The ring intervals widened as the daily increments approached the otolith edge. Total increment counts from the core to the edge of the larval fish otoliths ranged from 60 to 136 and averaged 90 increments.

Adult otoliths

As with the larval otoliths, enumerating daily increments surrounding the core of adult otoliths proved difficult because of the dense arrangements of increments. SEM micrographs revealed increments narrowing and becoming indistinguishable around 90 μm distal to the core along the frontal plane (Fig. 3A). At about 380 μm , the increments gradually widened so that about 200 increments were clearly observed with a regular periodicity. The distance between increments reached a maximum width of 3 to 4 μm in the first opaque zone (Fig. 3B) before narrowing again at about 1,000 μm . The increments became obscure even at high magnifications and were observed to merge into a deeply etched groove (about 1,400 μm from the nucleus), presumably the site of a translucent zone viewed under light microscopy (Fig. 3C). Toward the next opaque zone the increments widened and became easy to identify again. A similar sequential pattern was observed through the light microscope in both transverse and sagittal sections though distances varied owing to the different viewing axes.

Accessory primordia were clearly evident in the adult fish otoliths. These structures created disrup-

tions along the counting axis, adding to the difficulty of making reliable daily increment estimates. Total minimum daily increment counts (many increments were probably missed) from light microscope observations ranged from 190 to 353 increments, averaging 250 increments from the core to the first translucent zone.

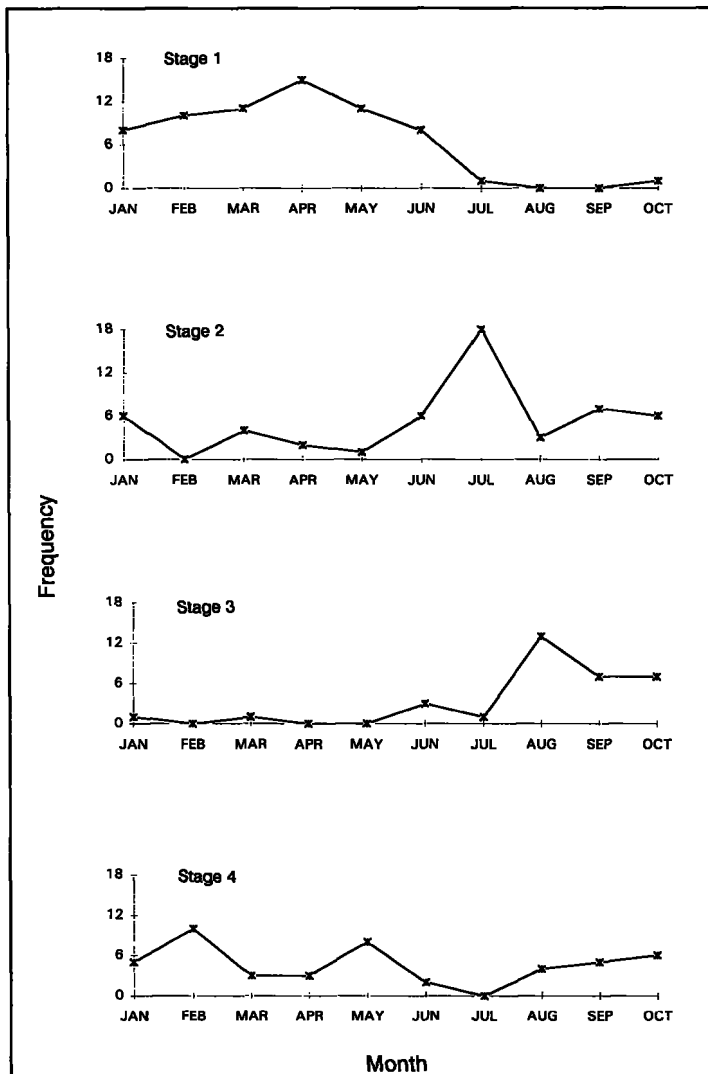


Figure 2

Results of marginal increment stage determination from otoliths with 2-3 translucent zones. Stage 1 = a translucent zone along the otolith growth margin; stage 2 = area of opaque growth between the otolith growth margin and adjacent translucent zone that is nearly one-fourth the size of the previously deposited opaque zone; stage 3 = area of opaque growth between the otolith edge and adjacent translucent zone that is nearly one-half the size of the previously deposited opaque zone; and stage 4 = area of opaque growth between the otolith edge and adjacent translucent zone that is nearly equivalent in size to the previously deposited opaque zone.

Seasonal length data

FOCI larval data FOCI data showed relatively small increases in Atka mackerel larval lengths from September to April, averaging about 1.5 mm per month. A more rapid increase in mean length appeared to occur after April. However, FOCI data for May and June were sparse; only two specimens were caught in May and 10 in June (Table 1). Lengths from Gorbunova (1962) also showed relatively small monthly increases in size for larval Atka mackerel and closely resembled lengths from FOCI larval data (Fig. 4).

NRIFSF offshore larval survey Average summer lengths (minimum and maximum lengths and sample size are in parentheses) of Atka mackerel caught from the NRIFSF offshore survey are 49 mm SL in June (39 mm SL-59 mm SL; $n=8$), 54 mm SL in July (46 mm SL-67 mm SL; $n=15$), and 101 mm SL in August (99 mm SL-104 mm SL; $n=2$).

AFSC-RACE bottom trawl survey The average summer length for one-translucent-zone fish was 250 mm FL (210 mm FL-290 mm FL; $n=43$), for two-translucent-zone fish it was 306 mm FL (240 mm FL-410 mm FL; $n=286$), and for three-translucent-zone fish it was 358 mm FL (310 mm FL-440 mm FL; $n=38$).

Discussion

Seasonality of translucent-zone formation

The highest frequencies of translucent-zone formation (stage 1) occurred around April. The period during which most otoliths exhibited the stage-1 pattern spanned at least 6 months, whereas the period exhibiting stage-2 and stage-3 patterns was relatively short but intense. In other words, the frequency of a relatively small opaque growth beyond the translucent zone (stage 2) peaked in July, and opaque growth doubled in size (stage 3) by August. This rapid otolith growth appeared to coincide with the spurt in somatic growth observed in summer-caught NRIFSF Atka mackerel. The bimodal appearance of the stage-4 pattern was probably due to the reader's confusion with the pseudo-translucent nature of the otolith edge (North, 1988) with the result that some stage-1 otoliths were classed as stage-4 otoliths. Nev-

ertheless, it appears evident that translucent-zone formation (stage 1) is most common in late winter to spring.

Comparisons of larval and adult otoliths

The increase in size between otoliths of spring-caught larvae and otoliths of adults with at least one translucent zone suggests that the first translucent zone is formed considerably later than the first April after fall hatching. Because study on the marginal increment identified late winter to spring as seasons of translucent-zone formation, it appears that the first translucent-zone is probably formed during the fish's second spring (after two winter seasons). Results from the daily increment counts did not conclusively support our hypothesis. Some support may be gleaned from the deposition pattern of the otolith daily increments viewed with light and SEM micrography where two regions of narrow increments were observed between the otolith core and the first translucent zone, suggesting two periods of slow growth, probably during the first two winters.

Seasonal length data

Seasonal larval length frequencies from FOCI data and Gorbunova (1962) were very similar, suggesting that the growth characteristics of the Kamchatka Atka mackerel do not differ greatly from those of the Northeastern Pacific fish during the first nine months of life. Therefore it would seem that length at age in the early years should be similar between Atka mackerel from the two regions.

When seasonal lengths from FOCI, NRIFSF larval surveys, and the AFSC-RACE summer bottom trawl survey are combined (Fig. 5), it becomes very apparent that spring-captured Atka mackerel at lengths of 180 mm FL (the smallest fish observed with a translucent zone) must have already lived through two winters, further support-

ing the hypothesis of a missing first-year translucent zone.

The various sites where Atka mackerel were found may provide clues to the early life history of this species. Life history changes, such as metamorphosis or

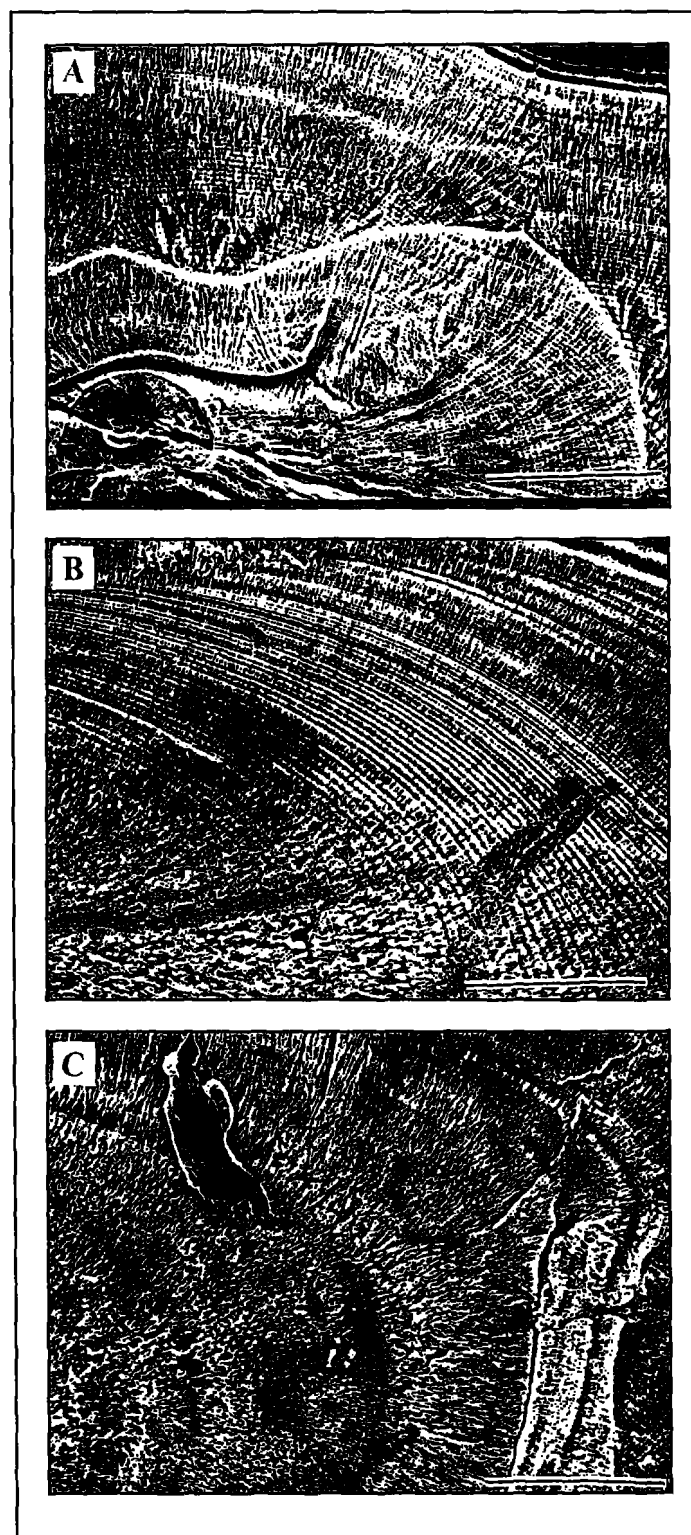
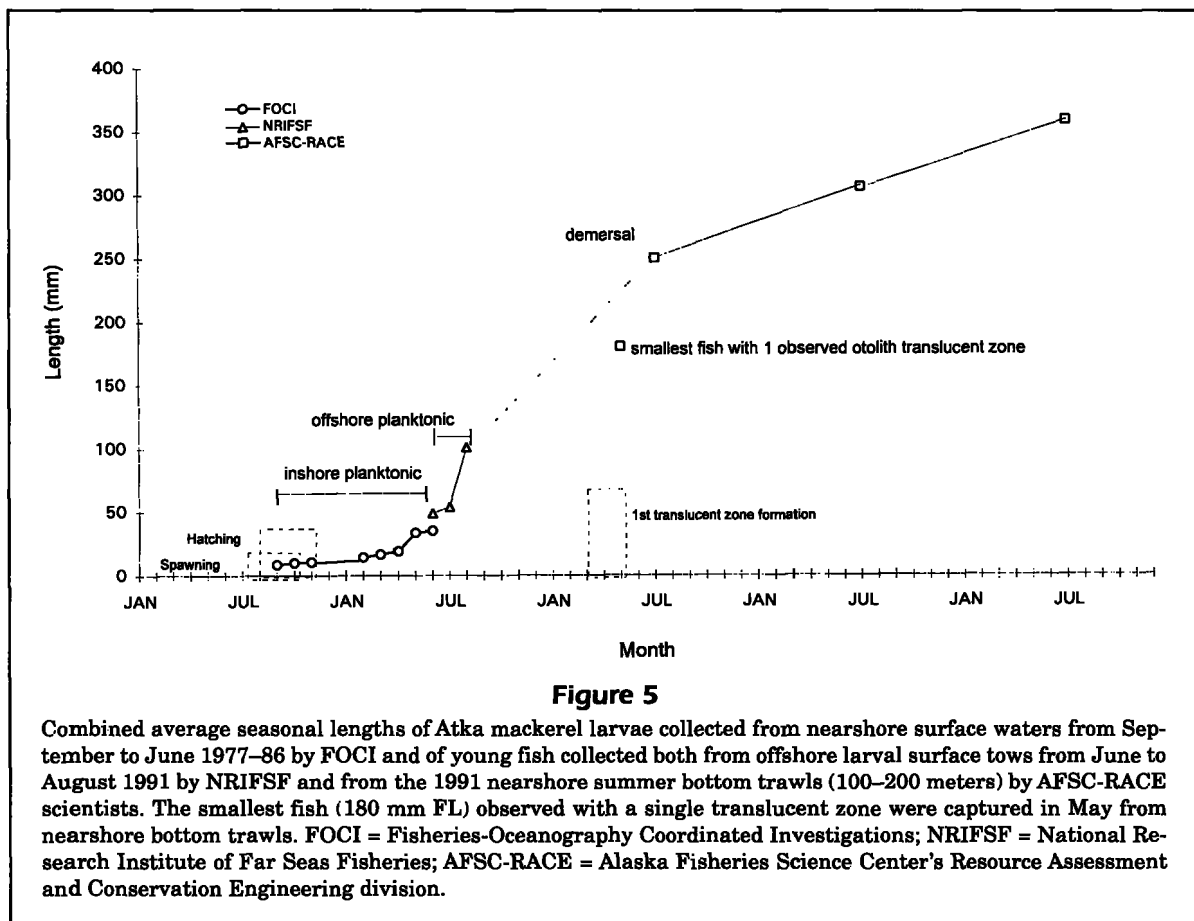
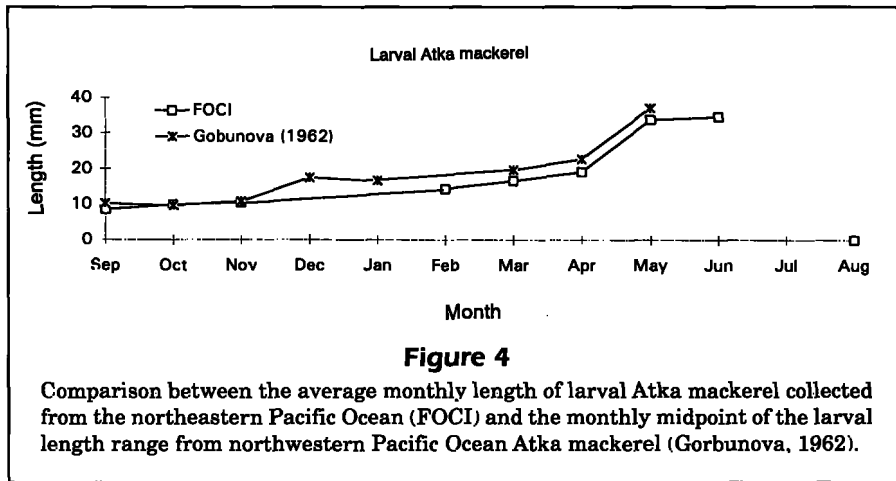


Figure 3

The following SEM micrographs were taken along frontal sections of otoliths with two translucent zones that came from fish 250 mm–280 mm FL captured during summer bottom trawls in 1991. (A) This panel shows a zone of very narrow increments surrounding the otolith core. Increments radiating from several accessory primordia are clearly evident. (B) Well-defined increments are observed with regular periodicity in the opaque zone proximal to the first translucent zone. (C) The increments narrow in width until they become obscure and disappear into the groove structure that is the first translucent zone. Bars = 50 μ m.

habitat changes, have been associated with accessory primordia formation in the otoliths of other fish species (Gartner, 1991; Sogard, 1991; Toole et al., 1993). Atka mackerel accessory primordia were found proximal to the first translucent zone in adult otoliths but none were observed in larval otoliths, suggesting that these structures were formed after their first April and before the following spring. The appear-

ance of the accessory primordia coincides with a time in the life history of Atka mackerel when young fish may be undergoing migration and habitat changes within the water column. Catch data from the three scientific surveys described in this study seemed to indicate that Atka mackerel migrate from nearshore surface waters, where larvae are found between fall hatching and the following spring, to offshore sur-



face waters in the summer. Between their first summer and their second spring, the young fish return to nearshore waters, settling to a semidemersal existence. It is during this second spring that the first translucent zone appears on the otolith. Perhaps the translucent zone does not form during the first spring because the larvae are still planktonic. The translucent zone in Atka mackerel otoliths may be a manifestation of changes in temperature and food availability along the ocean bottom.

Conclusions

When all available evidence regarding otolith characteristics and seasonal changes in size and habitat are combined, the most parsimonious explanation of these data is that Atka mackerel have survived two fall–winter periods prior to formation of the first translucent zone.

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